NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Technical Memorandum No. 86.

TESTING AIRPLANES IN FLIGHT:

Determining Position of Resultant of Action of Air
and Longitudinal Stability of an Airplane
at Different Angles of Attack.

By A Senouque.

From "Premier Congrès International de la Navigation
Aérienne," Paris, November, 1921, Vol. I.

April, 1922.

TESTING AIRPLANES IN FLIGHT.*

Determining Position of Resultant of Action of Air and Longitudinal Stability of an Airplane at Different Angles of Attack.

By A. Senouque.

Measurements made during flight with the triple recording device (formerly employed by Mr. Toussaint and by ourselves), which gives the horizontal and vertical speeds of an airplane and the angle it makes with the horizon, render it possible to calculate its lift C_L, its drag C_D, and the resultant R, of the action of the air both in magnitude and direction, but, with these data alone, it is impossible to determine the position of this resultant in the plane of symmetry of the airplane. We will also see how we may determine the position of R during flight and then calculate the variations in the stability of an airplane.

In order that an airplane shall not turn about an axis perpendicular to its plane of symmetry and passing through its center of gravity, the moment of the action of the air with reference to this point must be zero. If, for example, it is desired to fly at an angle of $6°$, while completely abandoning the elevator, the resultant of the action of the air for this angle of attack must pass through the center of gravity of the airplane. When, for any reason, the airplane attacks the air at a different angle for the above, $9°$, for example, the resultant R, will no

longer pass through the center of gravity and will tend to make
the airplane turn in one direction or the other. If the airplane
is stable, the moment of R will bring the airplane back toward
the angle of 6°. If it is poorly constructed, this moment will
carry it further and further away from the original angle of at-
tack. But when we would hold the airplane at this angle of attack
of 9°, we must annul the moment of R. For this purpose, we have
two ways at our disposal. By moving a weight on an airplane, we
can change the location of its center of gravity and bring it on
the resultant R for 9°, or we can adjust the lifting surfaces
of the airplane, so that the resultant for 9° shall pass through
the original center of gravity, as was the case when flying with
an incidence of 6°. In practice the second method is always em-
ployed, the shape of the lifting surfaces being modified by the
different positions given the elevator while climbing or descend-
ing. Hence, for each angle of attack, there is a corresponding
shape of the lifting surfaces which causes the stability of the
airplane to vary with the angle of attack. If we fly without
changing the position of the elevator, but only move the weight
on board and if we note the position of this weight for each an-
gle of attack, we can, in each instance, determine the position of
the center of gravity of the airplane, i.e., the point through
which the resultant of the action of the air will pass for the
given angle of attack.

This is how these determinations can be made in practice.
The above-mentioned triple recorder is taken on board, a record-

ing thermometer and another recording instrument, on the drum of which is recorded the variations in the position of the elevator. One climbs to about 1000 meters and then descends by gliding with the engine at its very lowest speed and changes the angle of attack every 30 seconds. On the records obtained, care is taken to make measurements only after the lapse of 15 seconds after changing the angle of attack, for only after this interval of time can the airplane be considered to have a constant speed. Several series of experiments are thus made, the position of the center of gravity of the airplane being changed in each series by means of heavier or lighter weights situated as far as possible from the center of gravity, so that a slight variation in the additional load causes a relatively large variation in the position of the center of gravity.

The triple recorder furnishes the necessary data for calculating the different values of C_L and C_D for the different angles of attack. The barograph and thermograph curves enable the correction of these data for the density of the air. With the corrected values of C_L and C_D we can calculate the magnitude and direction of R with reference to the path followed by the airplane. The position of the elevator for the different angles of attack is shown by the position of its control lever. Lastly, a very simple calculation or a direct measurement gives the location of the center of gravity of the airplane for each flight.

Let us indicate, for each series of flights without changing

the position of the center of gravity, the positions of the ele-
vator as ordinates and the corresponding angles of attack as ab-
scissas (Fig. 1). Let us further indicate (Fig. 2) on a certain
scale and with reference to an axis parallel to the wing chord,
the different positions of the center of gravity of the airplane
corresponding to the position of the elevator. When the airplane
is in normal flight, i.e. without additional weight, the posi-
tions of the elevator for the angle of attack are represented by
the line g (Fig. 1) and the resultant R of the action of the
air passes through C.G. (Fig. 2). For the angle of attack I, the
ordinate of the position of the elevator is F and the resultant
of the action of the air is an angle   with the path MN of the
airplane, which is inclined to the wing chord by an angle I
equal to the angle of attack. After placing a certain additional
load on the tail of the airplane, the center of gravity is at
C.G.' and the resultant of the action of the air at the different
angles of attack passes through this point, when the path of the
airplane is straight and the corresponding positions of the ele-
vator are represented by the curve g'. For the same position of
the elevator as in the first case, the angle of attack is I',
since we have F = F' and the resultant of the action of the air
is represented in magnitude, position and direction by the vec-
tor R'. Since the elevator occupies the same position in both
cases, the shape of the lifting surfaces has not changed and, for
this shape, we have all the elements of the reaction of the air

for the angles I and I' and can calculate the value of the sta-
bilizing couple for these angles of attack.

Let us suppose that the normal angle of attack is I and
that the center of gravity is at C.G. If, in a gust, the wind
attacks the lifting surfaces suddenly with the angle of attack
I', the resultant of the action of the air, which was R an in-
stant before, is now represented by the vector R'. It no longer
passes through the center of gravity of the airplane. It has,
therefore, with reference to the center of gravity, a moment
M = R'L. L is measured on Fig. 1. This is a stabilizing moment,
since it tends to return the airplane to the position of normal
flight with reference to the new direction of the wind.

For other loads placed on the tail of the airplane, we ob-
tain other curves for the positions of the elevator with refer-
ence to the angles of attack and we can determine the stabilizing
moment for other inclinations of the wind. When the airplane
flies, without additional load, at the angle of incidence I, we
can then trace the longitudinal stability curve of the airplane,
when it flies in a straight line with its elevator in the posi-
tion corresponding to the ordinate F.

We can make the same determinations for other positions of
the elevator and find whether the moment of the resultant of the
air with reference to the center of gravity of the airplane is
always stabilizing for all these positions, i.e. for all angles
of attack. If this moment does not give stability for all angles

of attack, it will be necessary to reduce the angle of attack of
the tail plane. On the contrary, if this stabilizing moment is
too high, it may be advantageous to reduce it by increasing the
angle of attack of the tail plane, so as to render the airplane
more maneuverable and thus lessen the work of the pilot. All
these tests give the value of the stability of the airplane only
during gliding flight. It is therefore desirable to try experi-
ments for determining this stability in horizontal flight with
the engine running at different speeds, since the slip stream
against the different parts of an airplane changes the value of
the reaction of the air. Moreover, if the axis of the propeller
is not parallel to the path followed by the airplane, the lifting
force of the latter may be either increased or diminished. Last-
ly, if the axis of the propeller does not pass through the center
of gravity of the airplane, it produces a couple which varies
with its speed of rotation. The stability also varies with the
distribution of the loads on the airplane. Thus with only the pi-
lot, the airplane may be either more or less stable than with sev-
eral passengers. We must therefore repeat the above tests with a
smaller supply of fuel and oil (to reduce the load) and also with
as large a load as the airplane can carry.

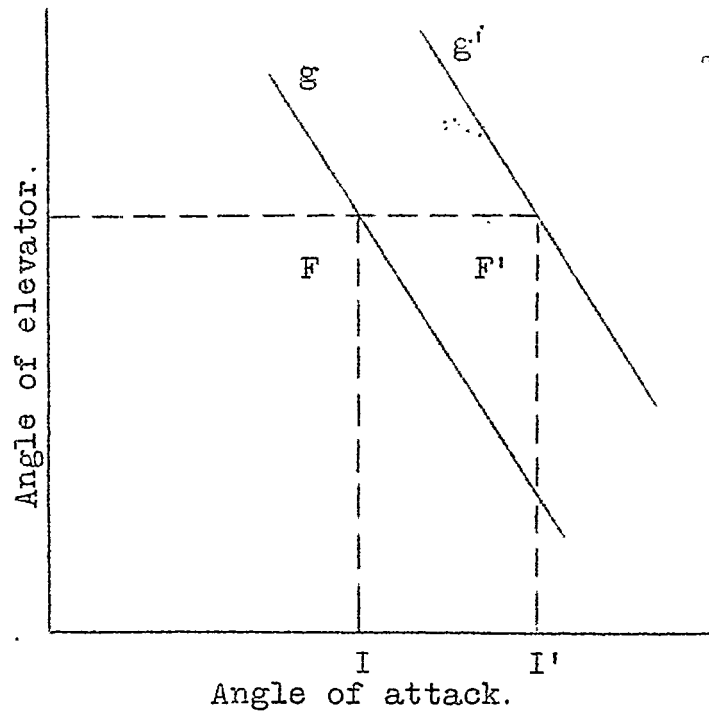Translated by the National Advisory Committee for Aeronautics.
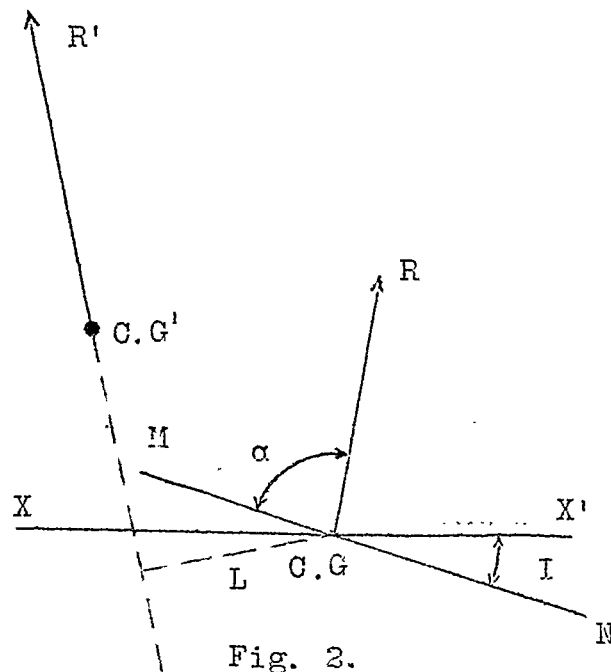
Fig. 1.

Fig. 2.